FEASIBILITY OF UNDERGROUND ELECTRICAL TRANSMISSION LINES FOR HIGHWAY CROSSINGS

October 1971

FINAL REPORT

FEASIBILITY OF UNDERGROUND ELECTRICAL TRANSMISSION LINES FOR HIGHWAY CROSSINGS

Prepared for

State of Montana
Department of Highways
Planning & Research Bureau

In cooperation with the
U. S. Department of Transportation
Federal Highway Administration

under

Electronics Research Laboratory Project #8-0009-762

Prepared by

Robert F. Durnford - Principal Investigator
J. Lester Knox - Research Engineer
Electronics Research Laboratory
Montana State University
Bozeman, MT 59715

ERL Report #1471

October 1971

TABLE OF CONTENTS

INDEX TO FIGURES

ABSTRACT

The intent of this report is to provide current information to serve as a guide to highway planners with regard to the placing of electrical utility lines underground.

The modern electrical power system is described briefly to provide a general background for the highway planner so that he will be aware of goals and problems of the utilities. This will aid in discussions with utilities about proposed replacement of overhead facilities with underground facilities and with the placing of new facilities underground.

The polyethelene insulated, concentric neutral cable is the cable that is now being utilized for underground distribution of power. This cable is described along with its major capabilities and limitations.

Underground cable installation procedures and methods are described and data is presented to aid in evaluating costs that are expected to be encountered in the installation.

SUMMARY

Use of this report in Highway Planning

It is possible to put almost any transmission line underground if one is willing to pay the price.

For voltages below 25 KV phase-to-ground (35KV phase-to-phase) the cost for underground lines can under certain conditions be as low as that for overhead lines. However, national cost averages recently published for utilities regularly putting in underground lines show cost ratios as low as 1.6:1 between underground and overhead, and costs as low as $.40/foot for large installation being put in under the most favorable conditions.

Figures 3-10 can be used to determine approximate costs for the most-used types of underground cable configurations. The straight lines marked "lower", "median" and "upper" were laid in using as a base, unit cost figures obtained from about thirty utilities in the northern and western United States.

For a small installation, all other things being equal, costs would range toward the "median to high" levels. Other factors causing increased costs are unfavorable terrain, (pavement, rocks, marshes, wooded areas, etc.), bad weather conditions, long travel times from construction base, high prices on construction materials, etc.

For transmission voltages between 25KV and 69 KV phase-to-ground, there is a possibility that future installations might be able to use the higher voltage concentric neutral cables now being introduced to the utility market, and thus obtain cost ratios that are less than 10:1 compared to an equivalent overhead line.

For transmission voltages above 69 KV, there seems to be no immediate prospect of technological improvements that will yield significant cost reductions. Thus for these voltages, cost ratios from 10:1 to 30:1 must be planned on. Each proposed installation will probably have to be estimated individually.

ACKNOWLEDGMENTS

The authors wish to express their appreciation to personnel of the more than 60 electric utility and electric equipment manufacturing companies whc have cooperated in this study through furnishing technical data, providing ideas, participating in discussions, and serving as hosts during field inspections.

Especially do we wish to thank the Northwest Electric Light and Power Association (NELPA) for permitting us to attend their 49th annual conference and the technical sessions of their Northwest Underground Distribution Committee.

Introduction

This project originated at the request of the Montana Highway Commission. It appeared that the placing of utility lines underground in the vicinity of highway crossings could offer many possible advantages as compared to the more conventional overhead lines. These advantages could include safety factors as well as esthetic factors. As examples, supporting structures for overhead line often are placed in close proximity to the traveled surface of highways. Hence, they may obscure the drivers view or may actually be physical obstructions in the case of accidents; the structures and the line conductors may detract from the natural beauty of the area.

There appeared to be sufficient advantages to placing utility lines underground to warrant a study to determine what factors and conditions are involved that make it feasible or not feasible to place any particular utility line underground and out of sight in the vicinity of highway crossings. As this project progressed, it became evident that there was interest in lines alongside of highways also, not just at the crossings.

There has been little information published that can serve as a guide to highway planners when they must negotiate with the electrical utilities relative to replacing existing overhead facilities with underground facilities when changes are necessitated by highway requirements, or relative to the construction of new underground instead of new overhead facilities when expansion of the utility system or capability is required. There has been a considerable interest in and much information has been published relating to underground residential distribution (URD) of electrical energy but much of this information is not useful to highway planners.

It is the intent of this study to make available to the highway planner information which will assist him in evaluating the feasibility and probable cost range of utility lines in the vicinity of highway facilities. It is not the intent of this report to discuss rerouting of existing overhead lines nor to discuss the improvement of esthetic properties as may be gained by color or form of the structures. These possibilities are certainly of importance to the highway planner but are beyond the scope of this study.

The Electric Power System

The following discussion of the overall electric power system is presented to acquaint the reader with terminology of the system, and to aid his understanding of the function of some of the system components as they are related to the subject of underground feasibility. This discussion is not intended to assist in the electrical design detail in any manner.

A power system can be visualized as consisting of four major divisions - 1) generation, 2) transmission, 3) distribution and 4) the ultimate consumer or customer. (Fig. 1)

Generation is that part of the system where energy is converted from other forms (hydraulic, fossil fuel, nuclear, etc.) into electrical energy. The actual generation plants normally must be sited at locations isolated from each other and at large distances from the consumer.

Transmission is that part of the system whereby large quantities of energy are conveyed over large distances. These transmission lines interconnect nearly all sections of the country to permit the

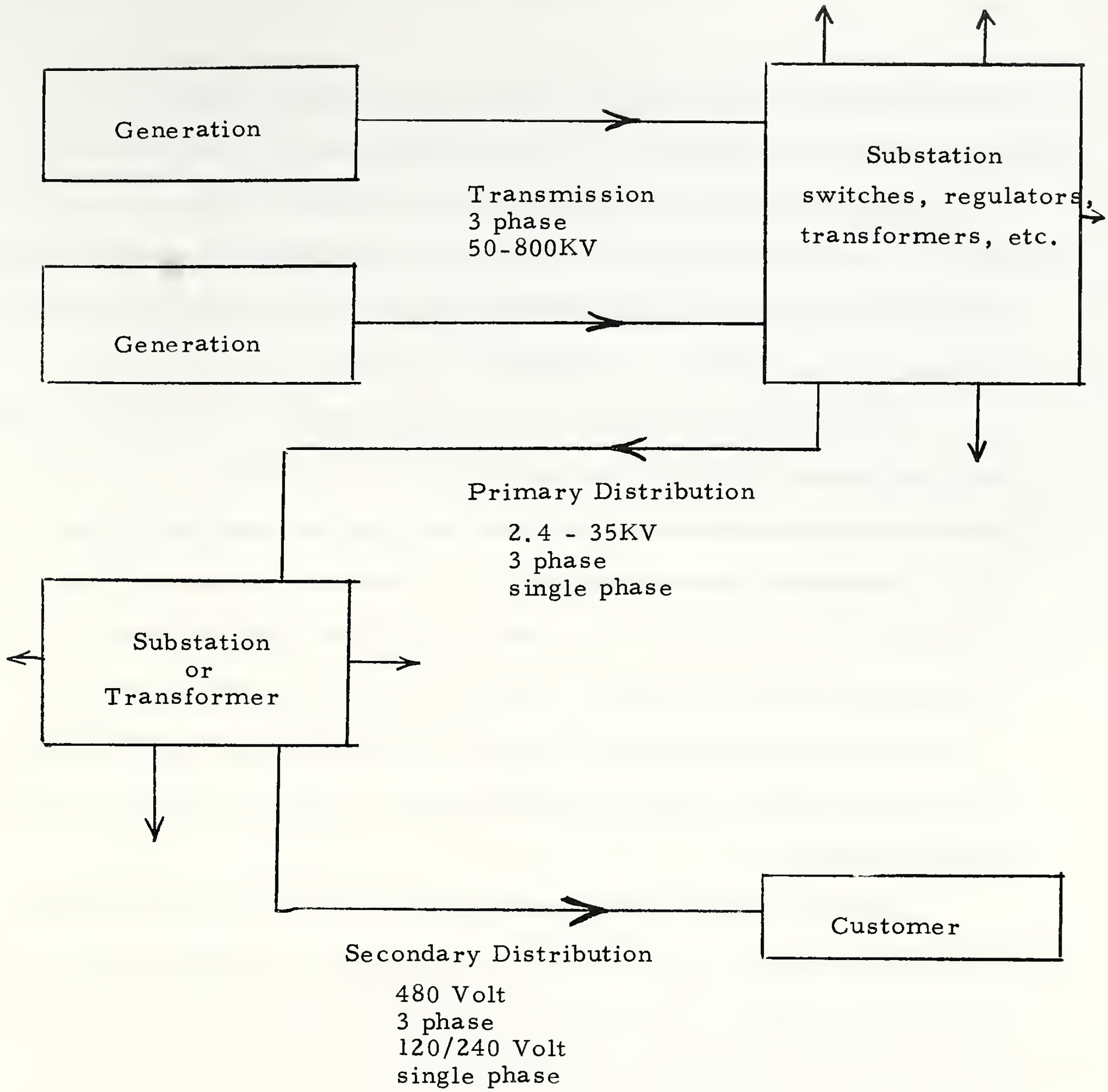


Figure 1
Block Diagram of Power Systems

economical and reliable supply of electrical energy. A transmission system requires substations for switching and control to assure reliable operation. Transmission systems today use principally three phase alternating current and operate between 50,000 volts and 800,000 volts. (50-800KV) There is at present some high voltage direct current transmission. Higher voltages will probably be utilized in the near future.

Distribution is that part of the system that carries the energy from the transmission system to the customer. The distribution system includes the substation transformers that reduce the high transmission voltages to a level suitable for distribution and the circuits that radiate from the substation to the customers. The primary distribution system from the substation to the load area normally operates between 2.4 KV and 34.5 KV. A distribution transformer is usually located near the customer to further reduce the voltage to the common 120/240 volt or other values as required by the customer.

Electrical power is the time rate of flow of electrical energy and the quantity of power required at any one instant is determined by the system customers. Since power is a function of the product of the system voltage in volts times the system current in amperes and other terms such as number of phases and power factor, the voltage value for transmission and distribution can be different. The larger the voltage, the smaller the current for a specified power. The larger voltages require more and better insulation while the larger currents require larger wires or conductors. It is thus apparent that economics will be a factor in system design as well as availability of adequate insulation and adequate current capability (ampacity) of the conductors.

Voltage regulation is a measure of the variation of system voltage from its standard value. Most electrical devices are sensitive to voltage change and it is therefore desirable to have the voltage remain constant at the device. Reliability is a measure of quality and continuous availability of power. The public is becoming more demanding of better and more reliable service as time goes on. Thus, the design maintenance and operation of the systems for reliability is extremely important.

The quantity of electrical energy used in the United States has been increasing at the approximate rate of doubling every ten years. It appears that this rate of increase will continue for the next few decades. This increase is due not only to population increase but to an increased use per capita due to new electrical devices. In addition, there are changes in load density patterns caused by trends toward urban living.

These changes require continual system modification both in the addition of new capability and in some cases of relocation of existing capability.

Quality of electric service

The electric utilities have been able to provide reliable service to the customers with very few interruptions. This reliability of approximately 99.98 percent has been accomplished by providing alternate circuits by switching systems such that many lines can be supplied from either or both ends and by maintaining spare equipment for rapid replacement of damaged components, etc. Voltage regulators and capacitors are often utilized to help maintain constant voltage under load change. Automatic circuit breakers, switches, sectionalizers and relays play a vital role in providing the reliable service that the public now expects.

There is considerable effort currently being expended to further the development of special underground equipment similar to the presently used overhead devices. It has not been satisfactory in general to merely adapt the overhead device to underground operation. In many cases, surface mounting rather than overhead or underground may be desirable such as the pad mounted transformers with built in terminals and switches. This, of course, requires adequate security for the safety of the public and protection against vandals.

System Growth

Historically, the quantity of electric power consumed has shown continued increase but not necessarily at a predictable rate in any one area. As a result, there is frequent need for revision of the system as loads increase.

An overhead system can often have its capacity increased by increasing the voltage at which it is operated. This modification can often be accomplished by merely increasing the size of the insulators and perhaps the spacing of the conductors. They can also be enlarged by replacing the conductors with larger conductors. Overhead lines may also be operated at heavy overloads for short periods because they are basically air cooled and inorganically insulated so that excess temperatures created may not be permanently damaging.

The underground system may not be as easily modified. The cables utilized and discussed further below, have a definite maximum voltage that the insulation can withstand. Hence, increase of operating voltage of an underground system is possible only if the cable has been operated previously at less than its maximum rating. Many cables that are to be installed

underground are selected to have capability larger than present needs. This increases the cost of the cable but may be less expensive than early replacement. In general, the underground line cannot be operated at appreciable overload without permanent damage to the insulation between conductors.

System Faults

The overhead electric system is subject to damage from such factors as wind, snow, and sleet storms, lightning, and automobile and aircraft accidents. There are insulator failures and conductors that break for various reasons causing the system to be deenergized temporarily or until repair is made. It should be noted that locating a fault is normally not difficult and it is normally readily accessible to repair men.

The underground system is also subject to damage. Voltage surges caused by switching of loads and surges caused by lightning on the overhead system and carried to the underground cable, may damage or destroy the insulation. The most common damage is caused by "dig-ins". (It is noteworthy that no mention has been found to date of any personal injury caused by dig-in to a buried power cable). One company reported 317 dig-ins in one year. One of the authors and dozens of others were without telephone service for approximately 48 hours recently because the same telephone cable was cut twice on consecutive days on a highway modification project. Repairmen worked around the clock restoring service both times.

Underground cables can be broken by earth movements such as result from freezing and thawing or other causes. Many assume that an underground cable is free of damage because it is out of sight, out of wind,

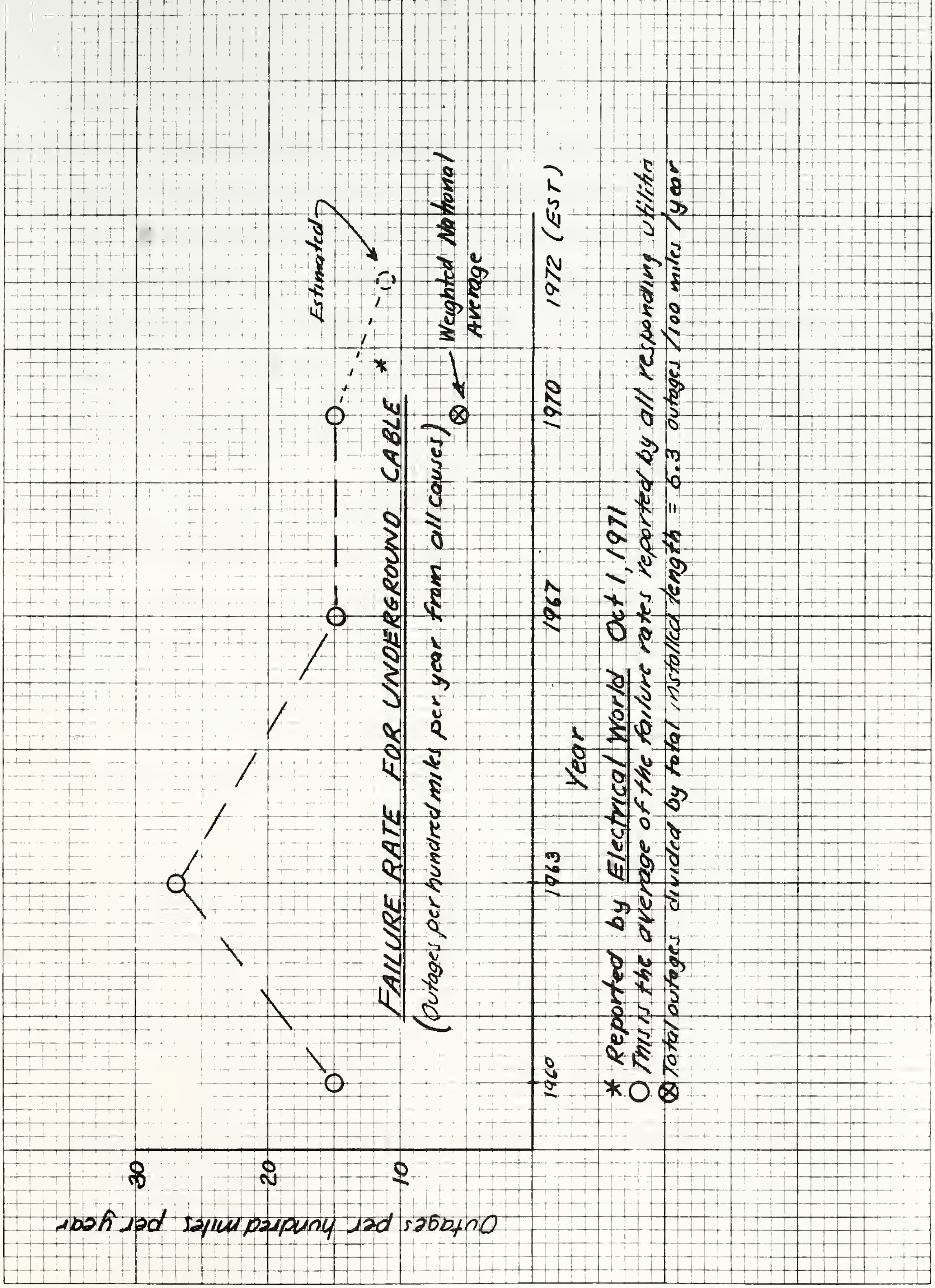
sleet and snow storms, etc. This may be true but faults in buried cables are more difficult to find, more expensive to repair and service is usually interrupted longer than from overhead faults. An underground line is often temporarily replaced with above ground facilities to restore service while the underground fault is searched for and repaired.

Figure 2 shows the average failure rate for underground cables in use by utilities surveyed in the last ten years and reported by Electrical World in the October 1, 1971 issue. The points plotted are the averages of the individual rates reported by each utility. However, the weighted national average for 1970, which is total outages divided by total installed length, is as shown, much less. This would seem to indicate that the utilities with the greatest installed length of cable were having lower failure rates.

Operation and Maintenance

Overhead lines require routine maintenance due to brush and tree trimming, insulator cleaning and replacement, hardware and pole replacement, etc. The majority of this maintenance can be done with the line energized and hence there is no service interruption.

Underground systems also require maintenance due to such factors as root and plant damage to cables and terminations, corrosion of connectors and splices, painting and restoring waterproofing and other protective coverings. Underground line maintenance typically requires deenergizing of the line and consequently, customer service interruption.



FAILURE RATE FOR UNDERGROUND CABLE
(Outages per hundred miles per year from all causes)
Estimated
Weighted National Average
Outages per hundred miles per year
30
20
10
1960
1963
1967
1970
1972 (EST)
Year
* Reported by Electrical World Oct 1, 1971
○ This is the average of the failure rates reported by all responding utilit
⊗ Total outages divided by total installed length = 6.3 outages/100 miles/year

Figure 2

Underground Cable

The development of polyethylene-insulated cables has had a tremendous influence on the overall practice of underground power system installation. High molecular weight low density polyethylene, is a moisture resistant thermoplastic material that offers a good balance between flexibility and mechanical properties for cable applications. Vulcanized or chemically cross-linked polyethylene is a comparatively new insulation that should withstand somewhat higher temperatures but it is also somewhat more expensive.

Polyethylene insulated cable with spiral concentric copper strands over the insulation is the most popular cable for underground distribution in the voltage ranges of 25 KV and less. The outer strands serve as a return current path and grounded neutral for primary circuits. Hence this same cable could be utilized for the common 20/34.5 KV three-phase system where the 34.5 KV is phase-to-phase voltage and the 20 KV is phase-to-neutral (ground) voltage and is the voltage appearing across the insulation of any one cable.

Higher voltage cables (above 35 KV) for underground use certainly exist. Recent advertisements indicate a few applications of the polyethylene type cable to higher voltages. Oil-impregnated paper insulation with lead sheath is still utilized but is quite expensive and justified only in special cases. Compressed gas insulated transmission lines are also possible. Cables for use at transmission voltages levels are expensive, as are splices and terminations. Each installation is nearly an entity of its own, hence no generalization of type or method is possible here.

Underground Cable Installation

Polyethylene concentric neutral cables are frequently directly buried in the ground without the use of conduit or duct systems. The cable may be buried in a trench or be plowed into the ground. Since it is somewhat susceptible to physical damage, experience appears to indicate that many failures can be attributed to damage at the time of installation. Hence crews must be well-trained and supervised.

Direct burial of the cable permits relatively good heat transfer to the surrounding soil. Placing the cable in a protective duct increases the installation cost and reduces the cable current capability but makes repair and/or replacement easier.

There are many varieties of implements designed to dig the trenches for cable installation. These go all of the way from large rotary saws capable of cutting through paving and frozen earth to the small convey or chain digger and even the hand shovel. It is permissible in many localities to place several facilities in the same trench such as electric power, telephone, cable TV, water and gas lines. However, the practice is prohibited in other areas. Where permitted it is often possible to reduce the cost for each utility because only one trench is necessary. However, extra time is normally necessary and there may be conflict of interest or labor problems. The common trench may also present problems later if one facility needs to have maintenance because the skills of each type of crew may be required for safety or other reasons. There is no advantage to the common trench except when several facilities are to be installed at one time.

Many implements have also been devised to place cables underground in one operation. Plows are available that can open the earth, feed the cable into the opening and reclose the hole. Some of these plows have vibrating structures designed to cause the finer particles of earth to fall near the cable and thus protect the cable from the larger rocks in the furrow. These cable plows normally carry the cable reel on themselves or on a trailer which they are pulling. Experience indicates that where large rocks or other obstacles are present, it is desirable to pre-rip ahead of the cable placing plow. The plow cannot back nor maneuver around large obstacles without cable damage, and hence there must be power enough to do the job. Cable plows can install cable at a rather rapid rate, perhaps a mile or two an hour in good working areas. They can install several cables at one time if required for the installation. Cable terminations and splices normally require digging that cannot be provided by the plow and hence add to the installation costs. The plow does not appear feasible except for the longer distances, say several thousands of feet.

Another problem presents itself to the installation when other facilities are already present. Care must be taken to avoid damage to other facilities. Since primary cables are installed at least 30" deep, they are often deeper than other facilities and hence not only must the power line be placed under but a splice is usually required to get it there because it is not practical to thread the remaining cable length under the other facility.

Highways, streets, railroads all must be crossed. (It appears desirable to have a protective conduit when placed under highways, etc. to protect the cable and to permit replacement without digging or reboring if the cable is damaged due to earth settling or shifting due to traffic). Methods of pushing conduit underground and of boring through and then placing conduit, have been developed and are being improved.

Underground Cable Ampacity

The current carrying capability (ampacity) of a conductor is determined by the amount of heat created in the conductor by this current and by the amount of heat that can be dissipated to the surrounding media without excessive temperatures. The maximum permissible temperature is normally determined by the type of electrical insulation. All electrical insulations inhibit the flow of heat to the surrounding media. Higher voltages require longer insulation paths which result in higher conductor temperatures for given currents.

The smaller size cables below the 25 KV range normally require the same size of conductor per ampere if direct buried as is required for overhead work. If the cable is buried in a conduit or duct, it may require the next larger size. However, the larger currents required in larger power circuits bring higher costs because the cable conductor must be larger than the equivalent overhead line to keep the temperature to values the insulation can withstand. The overhead conductor is cooled by air circulation but the underground conductor does not have this advantage. This is particularly true when several cables are near each

other and heat from one affects the temperature of the others. The utilization of three single-phase concentric neutral cables to form a three-phase system has caused excess heating due to currents induced in the three neutrals when there is separation of the cables and each was connected at the ends. This action is similar to a short circuited turn on a transformer. Cables with smaller concentric strands, higher resistance, and specially designed cable for three-phase use and special installation procedures have reduced this problem.

The concentric neutral cable has an electrical capacitance much higher than the equivalent overhead line. This capacitive effect may be large enough to require some form of compensation. This is normally not a problem except on long, lightly loaded cables or where one cable for one single phase circuit causes an unbalance of a three-phase system.

Underground Cable Life

The life of underground cables and associated equipment is expected to be approximately the same as overhead facilities. Most utilities surveyed planned for approximately 30 year life expectancy but stated that they did not have enough experience yet to be certain. There are many test facilities currently attempting to evaluate life expectancy by accelerated deterioration under controlled conditions. In a recent meeting, members of the NELPA organization reported they are attempting to isolate causes of a number of failures in polyethylene cable that is approximately eight years old.

There is reasonable certainty that over-voltage surges are damaging to the insulation and that they may have a progressive effect until failure

occurs. Hence, care must be excercised to avoid surges that may be caused by lightning or circuit switching.

There is also evidence that damage during installation may cause premature failure at a later date. There is apparently no method available at present that can accurately determine if a cable has been weakened at installation unless the insulation is severely damaged. Hence, damage may go undetected and cause future failures. This factor is of course of great concern and points up the need for care at installation as well as continuous care if the cable is uncovered or manipulated where it is brought to pad-mount transformer connections, etc.

There are also reported cases of cable neutral corrosion caused by soil conditions and or electrolysis. Cathodic protection and special coatings may be required in some areas. Splices, terminations and equipment other than the cable seem to be more susceptible than is the cable itself.

Overhead to Underground Transition

Each time that an underground cable system is connected to an overhead system there exists the possibility of voltage surges, caused by switching of loads or lightning surges that might not be harmful on the overhead system but which could damage or destroy the cable. Of course, faults on either system will influence the other. A transition between overhead and underground then should contain protective equipment appropriate for the protection of both.

A typical transition from overhead to a #2-15 KV single-phase cable might require the following components.

2 fused cut-outs	@ $25	$50
2 lightning arresters	@ $25	$50
2 6" insulators	@ $5.50	$11
brackets		$ 5
30 ft. 2" conduit		$30
2 potheads	@ $40	$80
conduit seal		$15
down guys		$16
40 ft. cable	@ $.30	$12
crew & equipment		$300
		$569

The example above is provided to indicate the general requirements of a transition. The components are catalog items in general and would differ in cost with size and type consistent with the particular installation.

Underground Transmission Lines

As was indicated in a preceding section of this report, electric power transmission lines are distinguished from distribution lines primarily by the length of line and voltage. Distribution voltages normally range between 2.4 KV and 34.5 KV phase-to-phase. Transmission voltages range from 50 KV up. The highest transmission voltage currently in commercial service in the U.S. is 765 KV.

During 1970, 12,200 miles of transmission line was installed in the U.S. Of this, 116 miles - less than 1% - was underground.

Esthetically speaking, most of the overhead lines installed would have been much less objectionable if installed underground. However,

the economic penalty at present is much too great. Cost ratios of underground to overhead for voltages above 50 KV range from 10:1 to 30:1 depending upon voltage levels and local conditions.

It is expected that as the demand for underground transmission cables increases that break-throughs in cable technology will occur, just as they have occurred at the distribution voltage levels, such that the cost penalty for underground transmission will decrease as it has for underground distribution.

Cost vs. Distance Curves

Figures 3 through 10 are cost vs. distance curves which can be used to estimate costs of underground electric power lines of the type most commonly used in underground residential distribution (URD). Curves are given only for 15 KV insulation class cables. These handle phase-to-phase voltages in Y-connected service up to 26 KV.

For voltages above this level, the next insulation class cable is rated at 25 KV line to shield and can be used up to 43.5 KV phase-to-phase in Y-connected service. An additional cable cost of approximately 20% to 40% above 15 KV prices would be typical. However, at present the costs of 25 KV insulation class distribution equipment (arrestors, breakers, etc.) are about $1\frac{1}{2}$ to 2 times those of 15 KV equipment. Overall costs of underground cables to be operated between 15 and 25 KV phase-to-ground would probably be about 1.3 to 1.7 times that of 15 KV. class lines.

There are solid dielectric direct burial cables on the market rated for 69 KV and 138 KV, however, they have had such limited use to date that it does not seem justifiable to predict costs at this time.

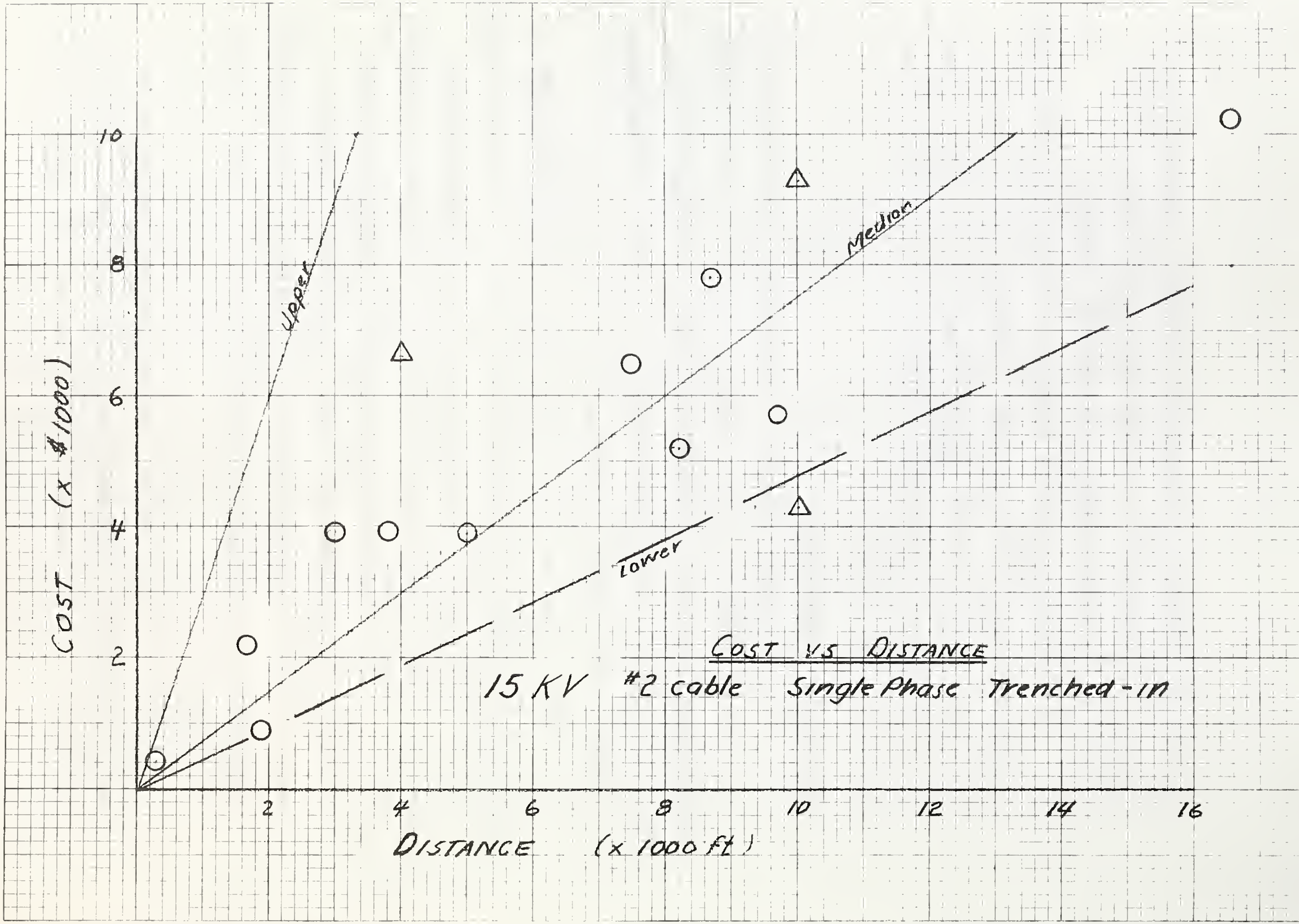
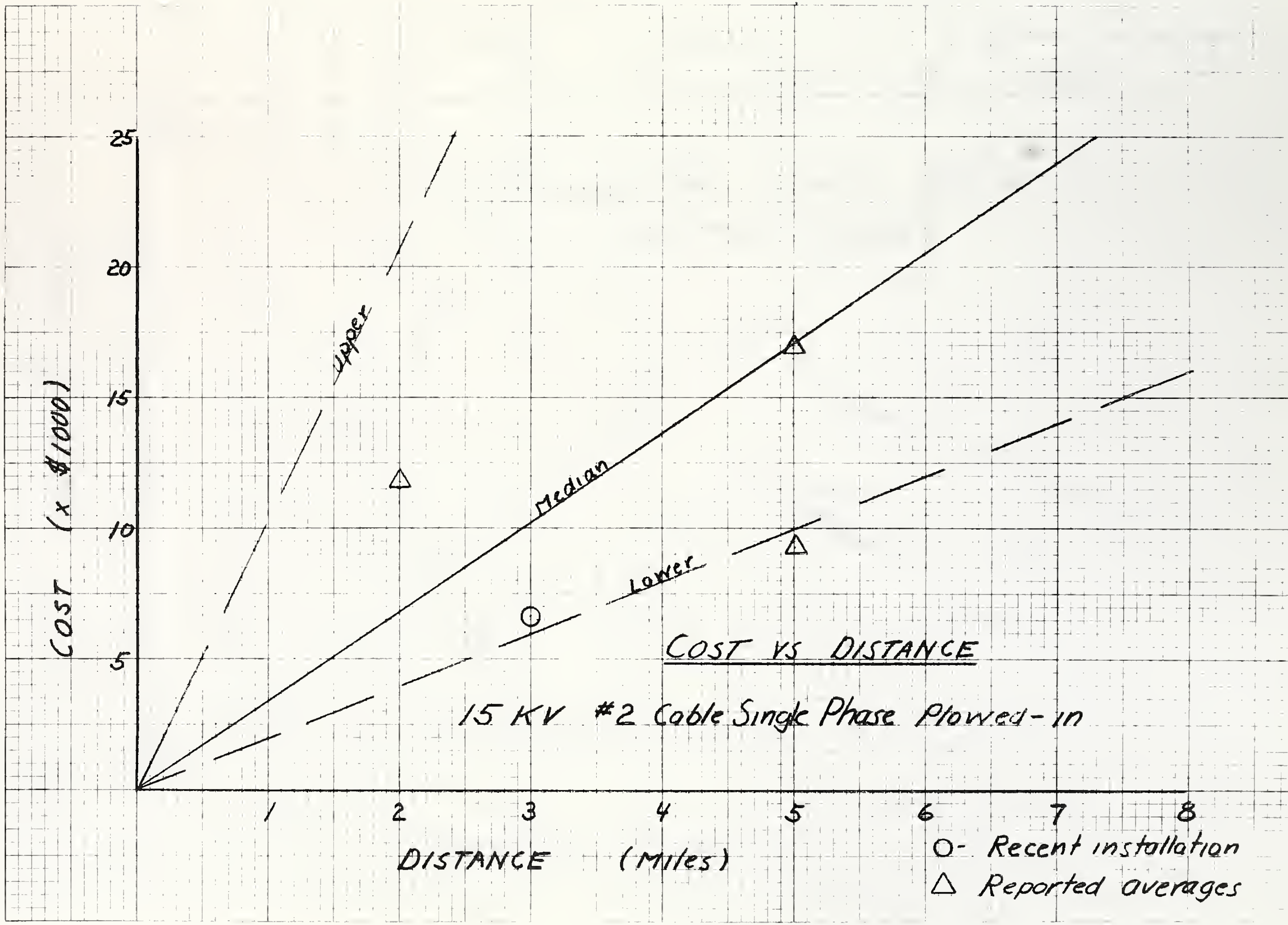

COST VS DISTANCE
15 KV #2 cable Single Phase Trenched-in
COST (x $1000)
DISTANCE (x 1000 ft)
Upper
Median
Lower
10
8
6
4
2
2
4
6
8
10
12
14
16

Figure 3



COST VS DISTANCE
15 KV #2 Cable Single Phase Plowed-in
COST (x $1000)
25
20
15
10
5
1
2
3
4
5
6
7
8
DISTANCE (Miles)
Upper
Median
Lower
O- Recent installation
△ Reported averages

Figure 4

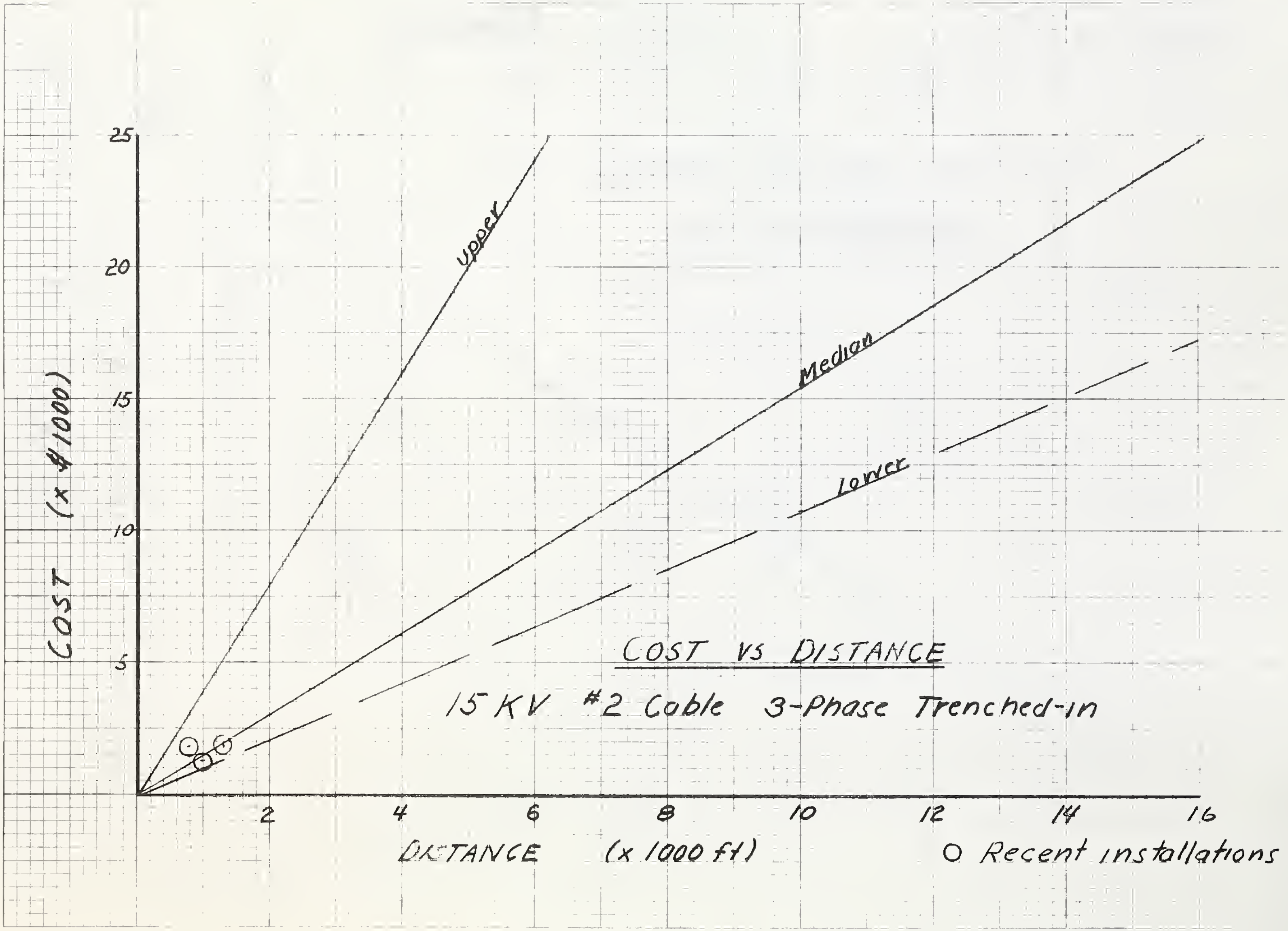

COST VS DISTANCE
15 KV #2 Cable 3-Phase Trenched-in
COST (x $1000)
25
20
15
10
5
2
4
6
8
10
12
14
16
DISTANCE (x 1000 ft)
Upper
Median
Lower
O Recent installations

Figure 5

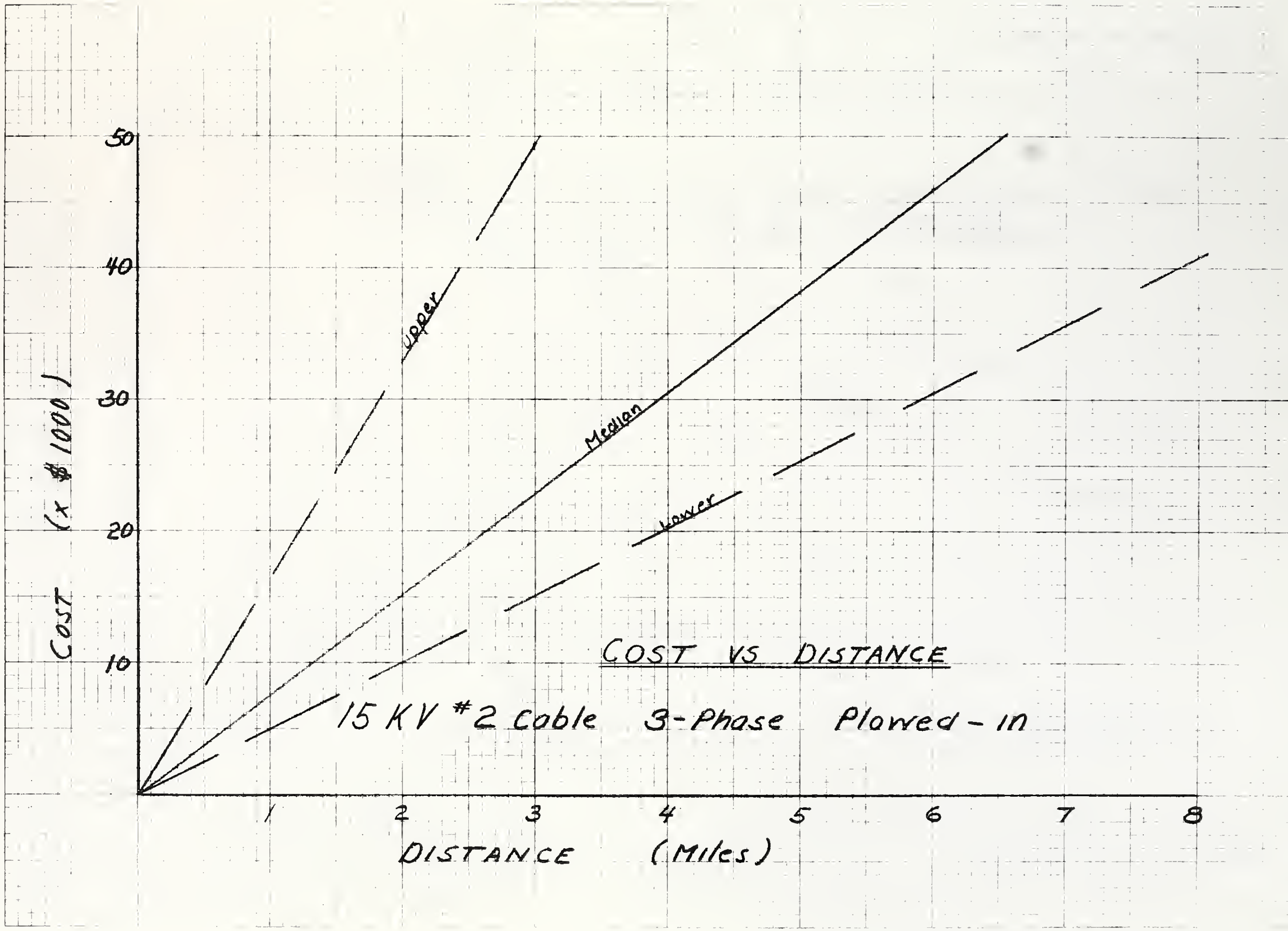

COST VS DISTANCE
15 KV #2 Cable 3-Phase Plowed-in
Upper
Median
Lower
COST (x $1000)
50
40
30
20
10
1
2
3
4
5
6
7
8
DISTANCE (Miles)

Figure 6

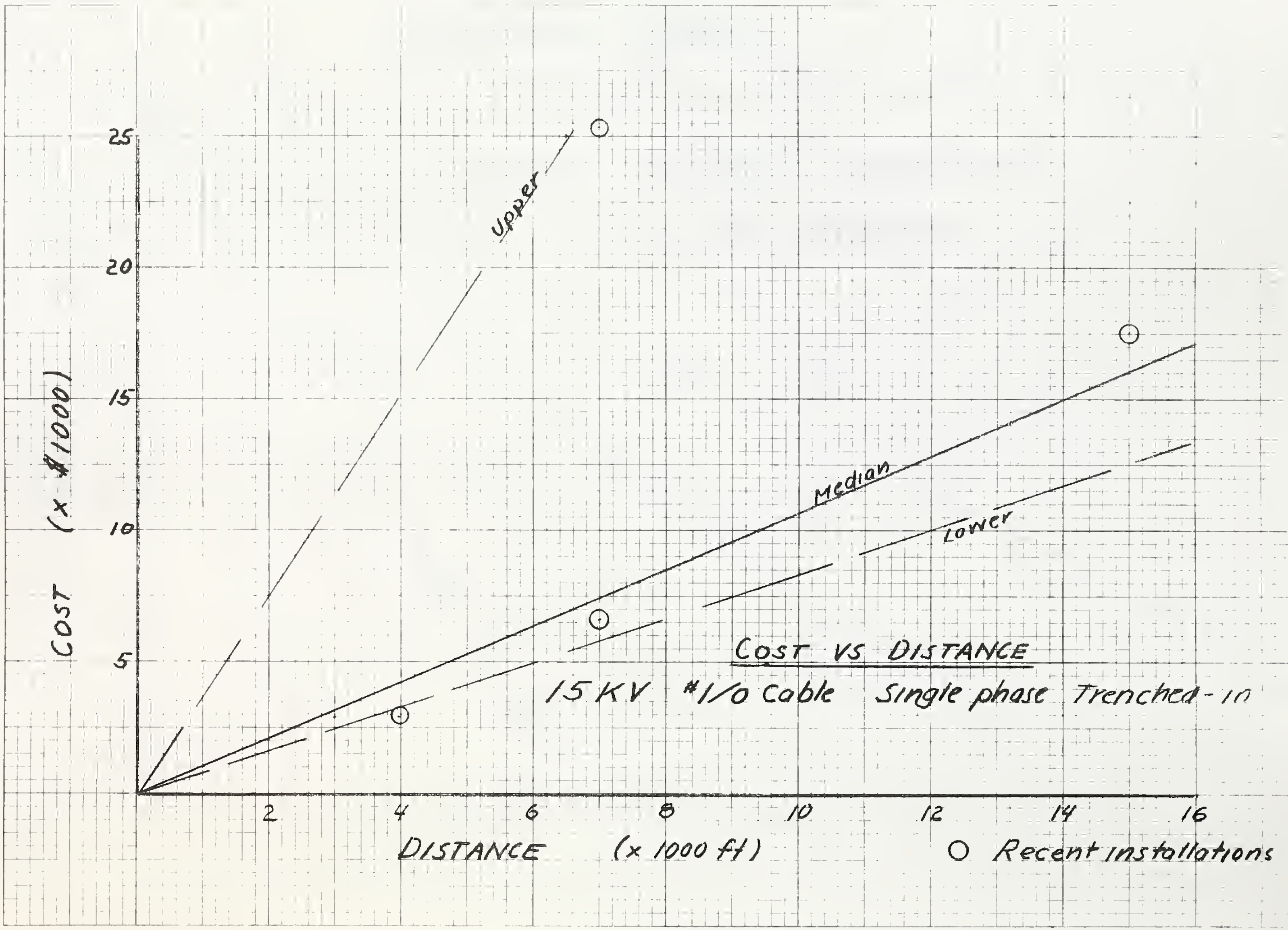

COST VS DISTANCE
15 KV #1/0 Cable Single phase Trenched-in
COST (x $1000)
25
20
15
10
5
DISTANCE (x 1000 ft)
2
4
6
8
10
12
14
16
Upper
Median
Lower
O Recent installations

Figure 7

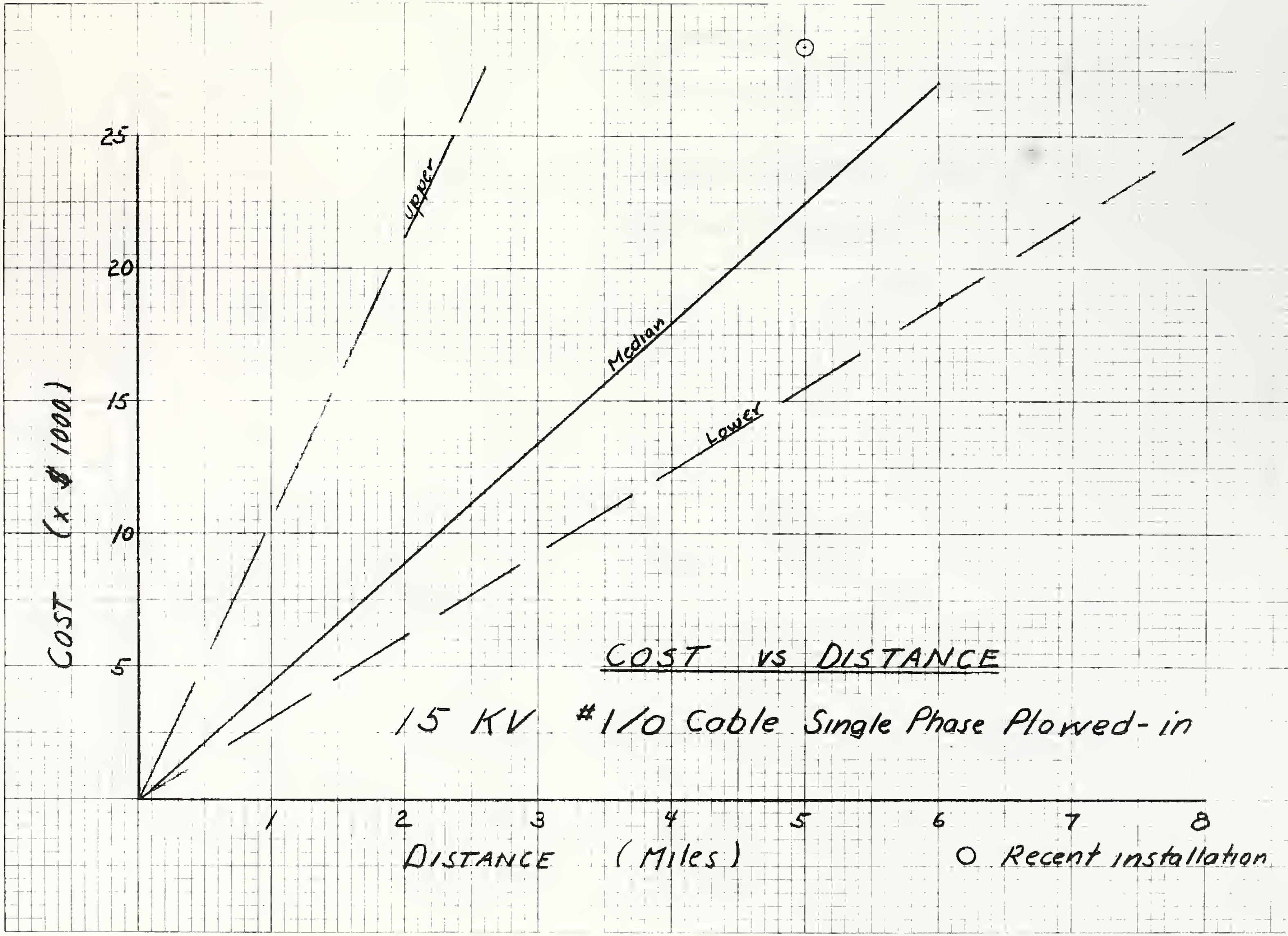

COST vs DISTANCE
15 KV #1/0 Cable Single Phase Plowed-in
COST (x $ 1000)
25
20
15
10
5
1
2
3
4
5
6
7
8
DISTANCE (Miles)
O Recent installation
Upper
Median
Lower

Figure 8

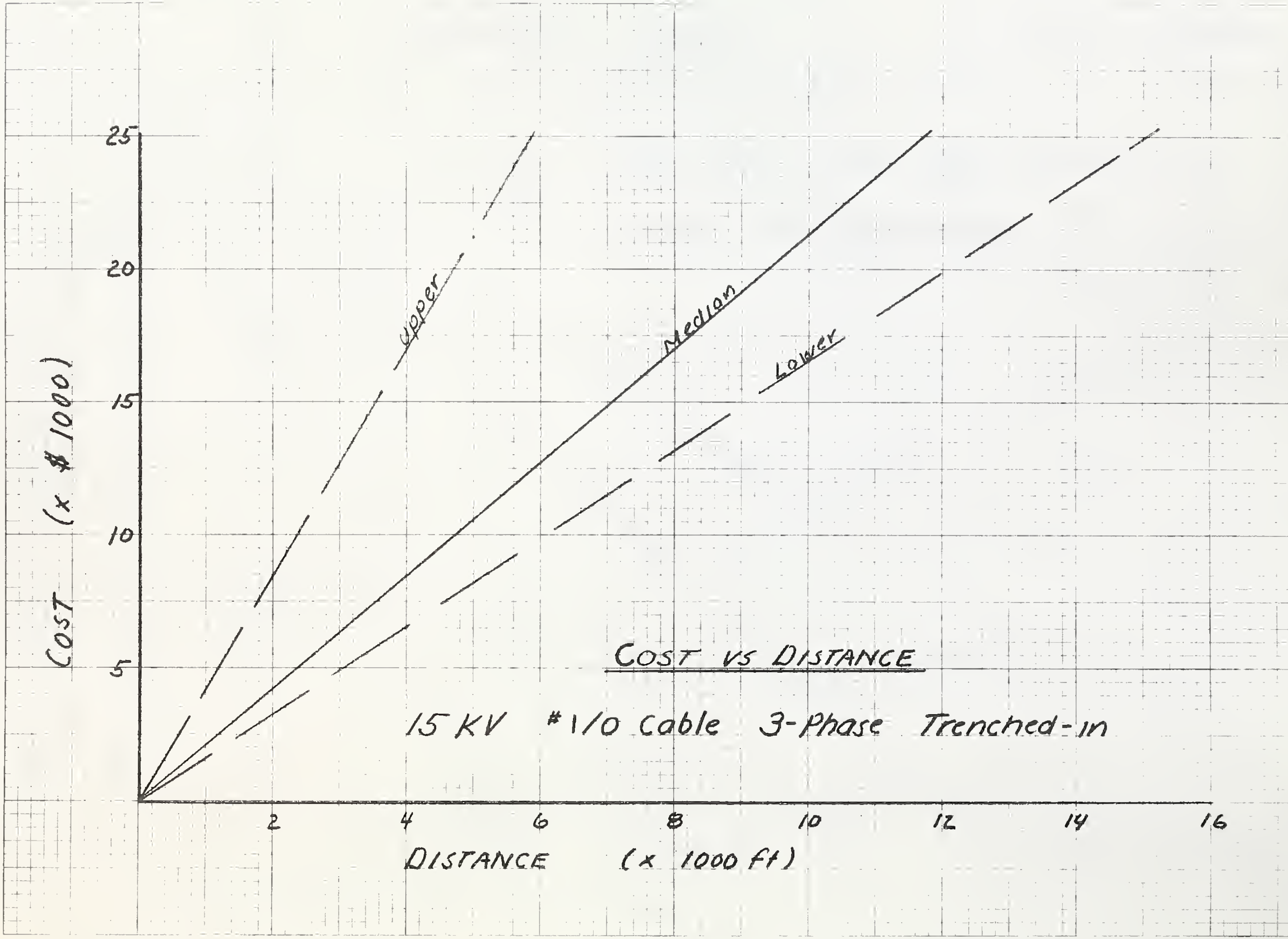

COST VS DISTANCE
15 KV #1/0 Cable 3-Phase Trenched-in
Upper
Median
Lower
COST (x $ 1000)
25
20
15
10
5
2
4
6
8
10
12
14
16
DISTANCE (x 1000 ft)

Figure 9

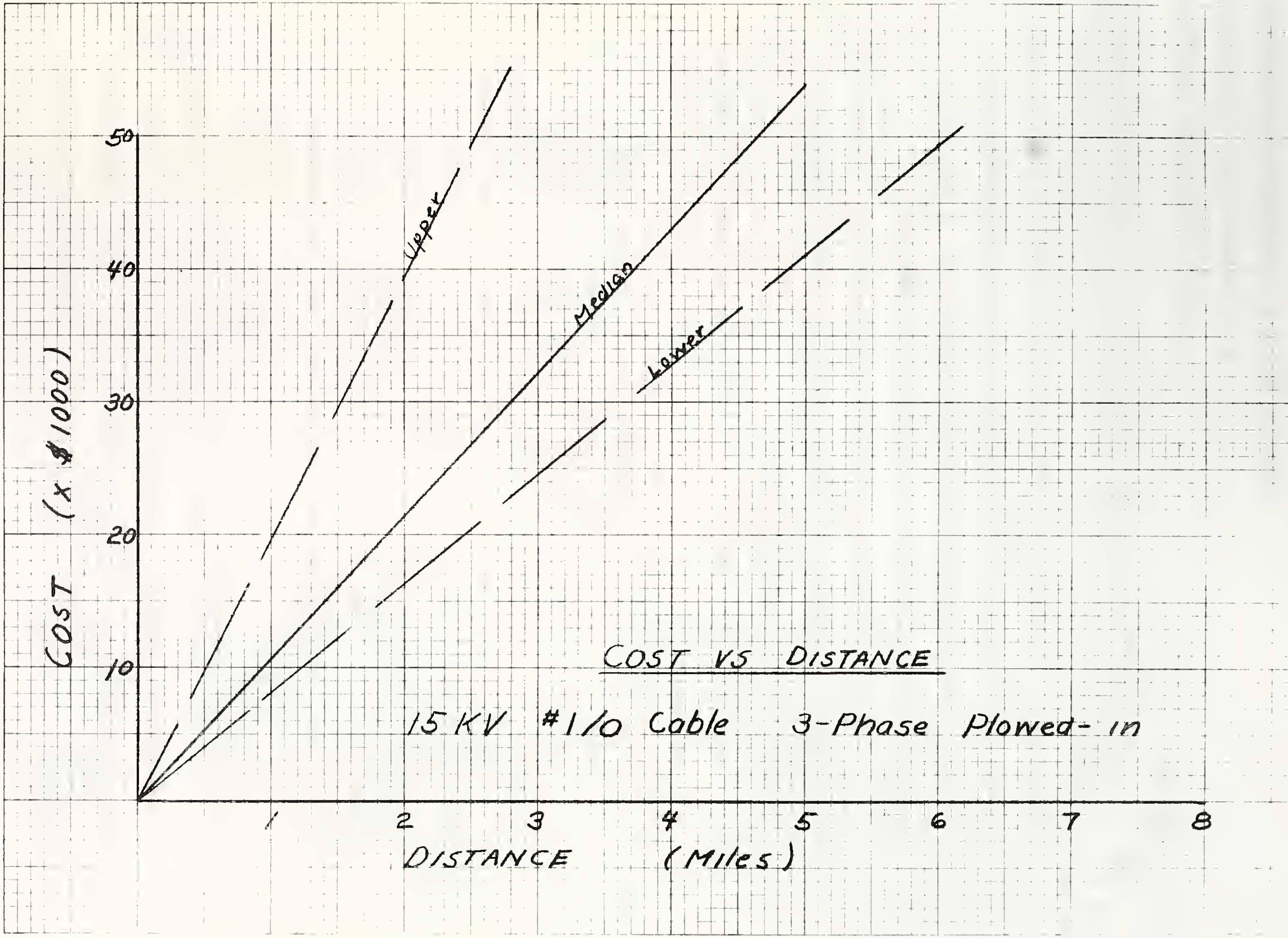

COST VS DISTANCE
15 KV #1/0 Cable 3-Phase Plowed-in
COST (x $1000)
DISTANCE (Miles)
Upper
Median
Lower
10
20
30
40
50
1
2
3
4
5
6
7
8

Figure 10

Survey of Utilities

During the period July-September 1971, a limited survey was conducted among most of the electric utilities serving Montana and the larger electric utilities in the Western United States. This was intended primarily to obtain up-to-date samples of cost data on underground electric transmission and distribution installations. A copy of the survey sheet and the letter of transmission is included.

A total of 54 letters were sent. Responses were received from 26 utilities, of which 7 had no data to report. 44 cost sheets were returned from the other 19 utilities.

Installations ranged from 20' @ $22/ft. to 40,000 @ $1.08/ft. with average per foot cost elements as follows:

	Samples		Low	Average	High
15 KV Cable	#2 URD	19	$.21	$.29	$.48/ft.
	#1 URD	2	.34	.37	.40 /ft.
25 KV	#1 URD	1	.36	.36	.36/ft.
Trenching Costs		18	.19	.57	1.06/ft.
Plowing Costs		11	.11	.28	.55/ft.
Splicing and Test Points		11	.012	.036	.075/ft.
Administrative Costs		7	.018	.034	.040/ft.

For 15 KV #2 URD Cable these gave average installed costs of

TOTAL Trenched	$.430	.932	1.65/ft.
TOTAL Plowed	.350	.640	1.13/ft.

Points corresponding to individual reports are plotted 0 while points corresponding to the averages above are plotted △ on Figures 3, 4 and 5. Where conduit had to be placed under highways, costs ranged from $1.00/ft. (rural, placed during highway construction) to $26.00/ft.

ELECTRONICS RESEARCH LABORATORY
MONTANA STATE UNIVERSITY
BOZEMAN, MONTANA 59715

(406) 587-3121 EXT. 257
(406) 587-7559

ERL

July 9, 1971

The Electronics Research Laboratory of Montana State University is currently conducting a study of the current status of putting electrical transmission and distribution lines underground. It is evident that there is a considerable quantity of direct buried cable being installed to operate at voltages less than 25 kv.

This study has progressed to the point where it would be desirable to have actual data for a number of installations of the last three years to provide statistical patterns of costs, methods of installation, difficulties encountered, etc.

It would help tremendously if you would take a few minutes to fill in the enclosed forms and return them in the return-addressed envelope. The information you provide will be used only in a statistical manner and it is not necessary to fill in your company name. If you have numerous installations would you please show at least three installations: one you feel to be typical, one of your more expensive and one of your least expensive installations.

We are enclosing a sample form filled out with values which appear to be somewhat typical of installations for which we have data at this time.

Thank you for your cooperation. We would appreciate as much information as you can give us.

Please indicate on the forms if you would like a statistical summary after the study has been completed.

Sincerely,

R F Durnford   J L Knox

Robert F. Durnford, J. Lester Knox

UNDERGROUND ELECTRICAL TRANSMISSION AND DISTRIBUTION

Company: ____

Classification: ________________ phase ____________ voltage ___________

Installation: Length __________ feet. Date installed ________________

Cable: Type ________________ size ______________ voltage ___________

Cable cost ______________________ per foot

Trenching cost ______________________ per foot

Plowing cost ______________________ per foot

Splicing cost (average) ______________________ per foot

Test point cost (average) ______________________ per foot

Other costs ______________________ per foot

______________________ per foot

______________________ per foot

Trenching or plowing equipment "move-in" cost: ____________________

Type of terrain: ____
(flat, hilly, mountainous, etc.)

Major obstacles: ____
(trees, rocks, rivers, etc.)

Conduit under highways: ________ ; if so cost ________________ per foot
(yes, no)

Additional Comments: ____

____

____

____

____

____

________ Check here if you would like a summary of data returned.

The information above will be utilized only in a statistical manner and only in the current feasibility study by the Electronics Research Laboratory at Montana State University.

(urban, hand digging, including re-paving) with the most often mentioned figure being \$4.00 to \$7.00 per foot for 3" conduit "punched through" the highway cross-section.

It should be noted that these cost figures do not include transformers, lightning arrestors, disconnects, etc. which must be included in the overall installation costs.

Many of the returns gave combined data for installations in urban areas utilizing several cable sizes and in some cases sharing trenching costs with other utilities. These did not readily lend themselves to inclusion in the tabulation above. Some representative samples follow:

Commercial 12.5 KV 3-Ø	750 MCM XLPE 5100 ft. (Includes vaults & PVC conduit)	\$10.75/ft.
Urban 12.5 KV 1-Ø	4/0 URD 1880' 2/0 URD 120' #2 URD 3200'	\$ 3.98/ft.
Commercial 7.2 KV 3-Ø	750 MCM 1000' (9 position concrete duct)	\$24.48/ft.
Suburban 13.2 KV 3-Ø	350 MCM Direct burial	\$ 3.52/ft.
Residential 120/240v 1-Ø	350/850 / 4/0 230' (Direct burial in customer trench)	\$ 3.25/ft.

Average Cost Ratio

By the end of 1970, 80 million feet of underground distribution cable had been installed in the United States, most of this for residential power supply. For this type of service standardization of materials and techniques has made possible reduction of installation costs to the point that for some special situations, underground installation was even cheaper than overhead. However, for the general average as shown in Figure 11, these ratios were between 1.25 and 1.7 with some utilities

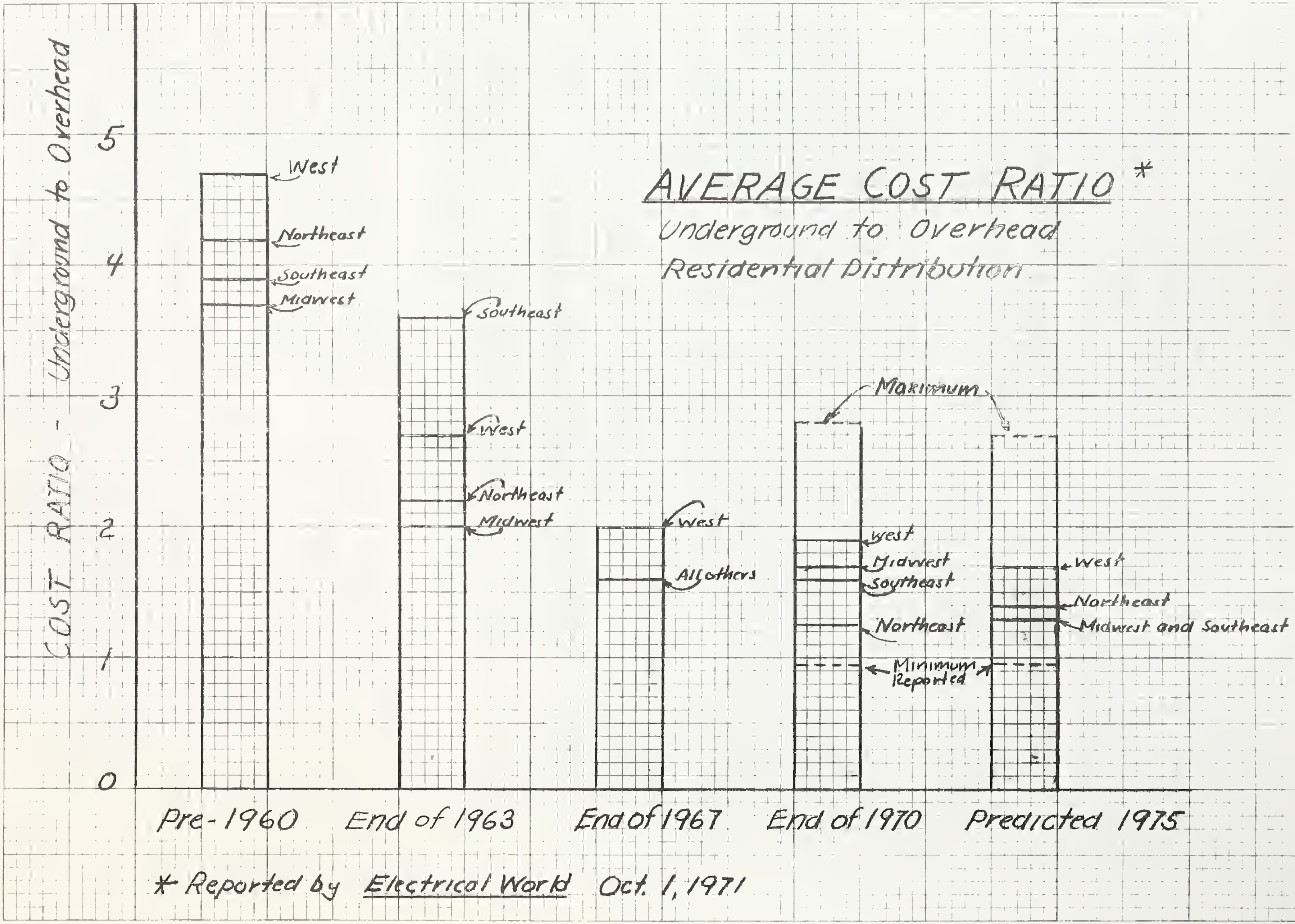

AVERAGE COST RATIO *
Underground to Overhead
Residential Distribution
COST RATIO - Underground to Overhead
5
4
3
2
1
0
West
Northeast
Southeast
Midwest
Southeast
West
Northeast
Midwest
West
All others
Maximum
West
Midwest
Southeast
Northeast
Minimum Reported
West
Northeast
Midwest and Southeast
Pre-1960
End of 1963
End of 1967
End of 1970
Predicted 1975
* Reported by Electrical World Oct. 1, 1971

Figure 11

reporting ratios as high as 2.8. No very large reduction of this ratio is projected for the next five years.

It should be pointed out that in most cases in which the highway designer desires to predict the cost of placing utilities underground, the situation will probably be far from optimum for the utility. Therefore, costs predicted by the lower cost ratios would probably be much lower than actual.

Sometimes low underground/overhead ratios do not necessarily mean low underground costs. Unfavorable terrain and construction conditions for overhead can sometimes make rather expensive underground construction look very attractive. This can be especially true where esthetic considerations dictate routing of overhead lines through remote and rugged terrain.

A short editorial entitled "Let's Face it: Underground Costs More" accompanying an article reporting on URD progress since 1969 in Electrical World seems sufficiently appropriate to quote in its entirety here. "One theme that appeared to run through utility reports at the just completed IEEE Special Technical Conference on Underground Distribution in Detroit was final acceptance of the social desirability of full commitment to underground residential distribution. In counterpoint, however, was the feeling that this commitment will not really be made until URD achieves cost parity with overhead construction. We feel that the concept of underground-to-overhead cost is a chimera, and, in itself, should not dictate service policy.

The ratio of underground to overhead costs has historically declined since the inception of URD. This year, for the first time, it has turned upward. The increase is undoubtedly impelled by sharply rising material costs and generous labor contract settlements. Objective analysis reveals little hope that the upward trend in these factors will change.

Adding to these upward pressures is growing recognition that service reliability must be enhanced as systems grow in extent and load density. Protective schemes and redundancies necessary to do this will further weaken the competitive cost position of URD. Whatever the cost of the equipment needed, much of which is as yet unavailable, it is specious to reason that it will be so inexpensive that it will not add even more to the current cost disparity between overhead and underground construction.

Economic improvements will undoubtedly be made in construction techniques and in equipment cost as new designs emerge and volume grows. Some few companies actually have achieved parity but this realistically appears to result from parochial conditions. The industrywide average of 1.7 to 1, and variations within regions ranging up to almost 3-to-1, are more representative.

We should recognize that many technical problems remain to be solved before URD can be accepted as fully compatible with this industry's high standards of reliability. But in our opinion, we must not let the concept of underground-to-overhead cost parity be a prerequisite to the full commitment of our technical energies to developing a system that meets those high standards.

Over the gate to the Spanish city of Toledo is carved a motto: "God says, 'Take whatever you want; but pay for it.'" In our opinion, if we wholeheartedly accept the desirability of URD for all new residential areas, we can achieve what we must. But we will have to pay for it."

SELECTED BIBLIOGRAPHY

This is a limited selection of articles which we believe would be of special value to one seeking information on the subject of underground power lines and is not intended to be a comprehensive bibliography on this subject.

"The Distribution of Electric Power" - A Report to the Federal Power Commission - The Distribution Technical Advisory Committee for the National Power Survey, June 1969.

"Working Committee on Utilities" - Report to the Vice President and to the Presidents Council on Recreation and Natural Beauty, Dec. 27, 1968.

"The Electric Utility Industry and the Environment" - A Report to the Citizens Advisory Committee on Recreation and Natural Beauty.

"Citizens Advisory Committee on Recreation and Natural Beauty"- Annual Report to the President and to the Presidents Council on Recreation and Natural Beauty, June 1968.

"Utility - Highway Briefing Session Notes - Public Roads Utility Policies", U.S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, March 21, 1969.

"Conference Record-Special Technical Conference on Underground Distribution", the IEEE Power Group, April 1969.

"Conference Record - Supplement Special Technical Conference on Underground Distribution", IEEE Power Group, December 1969.

"Design and Construction of Joint Buried Plant - Electric and Telephone", Rural Electric Administration, U.S. Department of Agriculture, Washington, D.C., 1967.

"Specifications and Drawings for Underground Electric Distribution", April, 1970, Rural Electrification Administration, U.S. Department of Agriculture.

Industry Briefs - (Announcement of first Underground Transmission Conference sponsored by IEEE scheduled for Pittsburgh, PA, May 1972), _Transmission and Distribution,_ P. 9, Vol. 23, No. 8, August 1971.

"Feature Issue: Underground Distribution", _Transmission and Distribution,_ December 1970, Vol. 22, No. 12.

"Featuring: Underground Distribution", Transmission and Distribution, Vol. 23, No. 9, September, 1971.

Hayes, William C., "A Special Report on URD Progress Since 1969", Electrical World, October 1, 1971, pp. 47-54.

"Rome Cable UD Technical Manual", Third Edition, Rome Cable, Rome, New York.

"Engineering Data for Electrical Cables", The Okonite Company, Wire and Cable Division - a subsidiary of Ling-Temco-Vought, Inc., Passaic, New Jersey, Bulletin 23.1.0.

Anaconda URD Cable - Catalog, Anaconda Wire and Cable Co., Wire and Cable Division, 605 3rd Ave. New York, N.Y. 10016, December 1969.

Unishield - Catalog and specifications summary on Medium Voltage Power Cable 5KV-35KV, Anaconda Wire and Cable Co., Wire and Cable Division, 605 3rd Ave., New York, N.Y., May 1971.

Porter, Alex G., "Underground for Rural Areas", IEEE Transactions on Industry and General Applications, Vol. IGA-6, No. 1, January/February 1970, pp. 71-73.

Lethert, C.W., Slothower, J.C., "Burial of Feeders to Cost $100 Million", Electrical World, February 17, 1969, pp. 32-33.

Berkhan, I.O., "Staged Faults Check URD Protection", Electrical World, July 15, 1971, pp. 46-47.

"Study SF_6 - Insulated Submarine Circuits", Electrical World, July 15, 1971, p. 49.

"Phone Number Set to Prevent Dig-Ins", Electrical World, Feb. 1, 1971, p. 61.

Datres, Fred S., "UD Project hits $1-Million Mark", Electrical World, August 1, 1971, pp. 46-48.

Capra, R.L. et al., "Underground Distribution System Design for Reliability", IEEE Trans Power Apparatus and Systems, 88:834-41, June 1969.

Hollingsworth, D.T., "Underground Power Cable - Past, Present and Future", Electronics and Power, 15:316-19, September 1969.

Scmitz, W.T., "URD Cable Sizes Chosen by Lifetime Loss Evaluation", Electrical World, 72:32-3, July 28, 1969.

Holcum, K., "Underground Transmission", Power Engineering, 71:58-9, November 1967.

"How to Troubleshoot Medium-Voltage Power Cable", C.J. Oatess, IEEE Transactions on Industry and General Applications, Vol. IGA-5, No. 2, March/April 1969, pp. 163-168.

"See UD Users Paying Tab", Electrical World, June 29, 1970, p. 18.

"The Modular Approach to URD", The Line, McGraw-Edison Power Systems Division, First Quarter, 1969.

Gorski, A.D., "Direct-Buried Capacitor Tests show Promise", Transmission and Distribution, November 1971, Vol. 23, No. 11, pp. 30-33.

"Putting 400 KV Cables Underground", Engineering, 205:816, May 31, 1968.

Williams, H.B. and Chu, S.C.,"Computer Solution of E.H.V. Underground Cable Cooling Problems", Proc IEEE, 115:407-17, March 1968.

"Sequence Impedances of Underground Concentric Neutral Cable", R.C. Ender, The Line, McGraw-Edison Power Systems Division, Second Quarter 1971, pp. 15-20.